

# APPARENT ACCELERATION AND AN ALTERNATIVE CONCORDANCE FROM CAUSAL BACKREACTION

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A phenomenological formalism is presented in which the apparent acceleration of the universe is generated by cosmic structure formation, without resort to Dark Energy, modifications to gravity, or a local void. The observed acceleration results from the combined effect of innumerable local perturbations due to individually virializing systems, overlapping together in a smoothly-inhomogeneous adjustment of the FRW metric, in a process governed by the causal flow of inhomogeneity information outward from each clumped system. After noting how common arguments claiming to limit backreaction are physically unrealistic, models are presented which fit the supernova luminosity distance data essentially as well as  $\Lambda$ CDM, while bringing several important cosmological parameters to a new Concordance. These goals are all achieved with a second-generation version of our formalism that accounts for the negative feedback of Causal Backreaction upon itself due to the slowed propagation of gravitational inhomogeneity information.

*Keywords:* Cosmic acceleration; Backreaction; Cosmological parameters; Dark energy.

## Introduction and Overview for Causal Backreaction

Evidence that the expansion rate of the universe is accelerating<sup>1,2</sup> has led to the conclusion that the dominant cosmic component is “Dark Energy”, a negative pressure (yet smoothly-distributed) material. But given problems related to magnitude fine-tuning<sup>3</sup> and “coincidences”<sup>4</sup> for a Cosmological Constant ( $\Lambda$ ) – and more unknowns for evolving forms of Dark Energy – an attractive alternative is known as “backreaction”, in which the (apparent) acceleration is a natural result of the ever-increasing inhomogeneity of the structure-forming universe (see, e.g., Refs. 5–9).

Presently, backreaction is not widely considered to be a viable method for achieving the observed acceleration.<sup>10</sup> Elsewhere,<sup>11</sup> I discuss how this seeming inadequacy of backreaction is likely due to the neglect of crucial physics via the use of overly trivial backreaction models. Some neglected physics includes: the dropping of vorticity for the virialization of stabilized structures; the dropping of “small amplitude” (but *cumulatively* important) terms in perturbation theory such as time derivatives, and velocity terms at least up to  $O[(v/c)^2]$ ; the neglect of tensor components and ‘gravitomagnetic’ terms, which carry gravitational perturbation information *causally*, at  $c$ ; the neglect of the cumulative *overlap* of different perturbations, artificially isolating each one from all others (they just “fall out of the expansion”), as in Swiss-Cheese models; and the debatable view (from Newtonian cosmology) that (individually) Newtonian-strength perturbations must yield essentially no backreaction.

Our approach here, in contrast, is to try to include *all* of the necessary physics of backreaction – even at the cost of using a very simplified model – rather than using a more sophisticated (or even exact) model of a *physically* simplified universe.

Utilizing the straightforward nature of the “before” vs. “after” cosmic states – that is, quantifying the total effect of the transition from smooth universe to ‘fully clustered’ – it can be argued<sup>11</sup> that the net effect of the formation of a vorticity-stabilized, virialized cluster far from a given observation point  $P$ , should be the simple addition of the Newtonian metric perturbation due to that cluster’s stabilized mass, to the overall (initially FRW) metric at  $P$ . For any point  $P$ , since the number of perturbing contributions increases with distance as  $r^2$ , but each contribution only weakens as  $1/r$ , the summed effect of all such contributions can become dominantly large – limited only by the look-back distance out to which an observer at  $P$  can ‘see’ stabilized structures, at that given time. The total metric perturbation (at *any* given observation point, in a “smoothly-inhomogeneous” universe) as a function of time,  $I(t)$ , is thus given by an integral over the (retarded) clumping that is felt from great distances at the observation point, as per Eq. 1 (and as depicted in Fig. 1):

$$I(t) = \int_0^{\alpha_{\max}(t, t_{\text{init}})} \{12 \Psi[t_{\text{ret}}(t, \alpha)] [(t_0/t)^{2/3}]\} \alpha d\alpha . \quad (1)$$

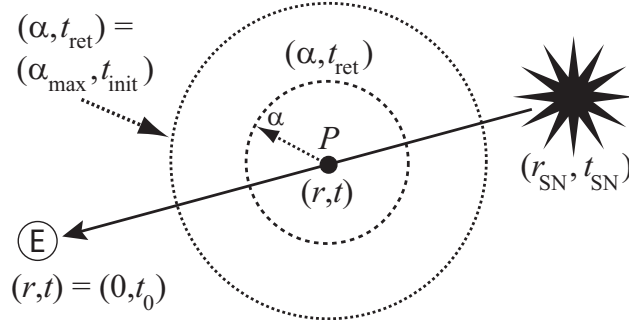


Fig. 1. Geometry for computing the inhomogeneity-perturbed metric at each point along the integrated path of a light ray from a supernova to our observation point at Earth.

To an observer at  $P$ , new clustered masses thus seem to ‘appear’ over time (as attractive, perturbing forces) as the material within each one transitions from smoothly distributed and almost motionless, to clumped and vorticity-stabilized. And though each such perturbation is ‘Newtonian’ in strength (as seen at  $P$ ), the total, summed metric perturbation will grow ever stronger as more virialized clusters ‘come into view’, eventually becoming strong enough to generate the apparent acceleration. This accumulation of perturbation effects from cosmologically-distant new structures, coming in towards  $P$  at speed  $c$ , is called “Causal Updating”.<sup>11</sup>

Averaging over clumps distributed randomly in direction, we get the metric:

$$ds^2 = -c^2[1 - I(t)] dt^2 + \{[a_{\text{MD}}(t)]^2 [1 + (1/3)I(t)]\} |d\vec{r}|^2 . \quad (2)$$

This is the final metric (computed for any given “clumping evolution model”,  $\Psi[t]$ ) to be used for calculating Hubble curves, and all cosmological parameters of interest.

Though several models were found in Ref. 11 which provided acceptable fits to the SCP Union1 SNIa data,<sup>12</sup> those initial backreaction simulations neglected an important complication: the fact that *old* metric perturbations from pre-existing structures slows down all *future* propagation of inhomogeneity information (from new structures, from old structures even farther away, etc.). This weakens Causal Updating, so that Causal Backreaction has a negative feedback upon itself (making an “eternal” acceleration very unlikely here). The Causal Backreaction response to clustering is therefore ‘recursive’ and nonlinear in terms of response versus clustering strength, and thus a second-generation model of Causal Backreaction was designed to incorporate the effects of these “Recursive Nonlinearities” (as distinct from *gravitational* nonlinearities). This new formalism, and a full suite of simulation runs, fit results, and cosmological parameters obtained with it, are given in Ref. 13.

The principal result of this study, is that astrophysically realistic Causal Backreaction models can indeed be chosen which successfully mimic the apparent acceleration generically attributed to  $\Lambda$ , but without any form of Dark Energy, Voids, etc. Some of these models, plotted against the Union1 SNIa data, are shown in Fig. 2.

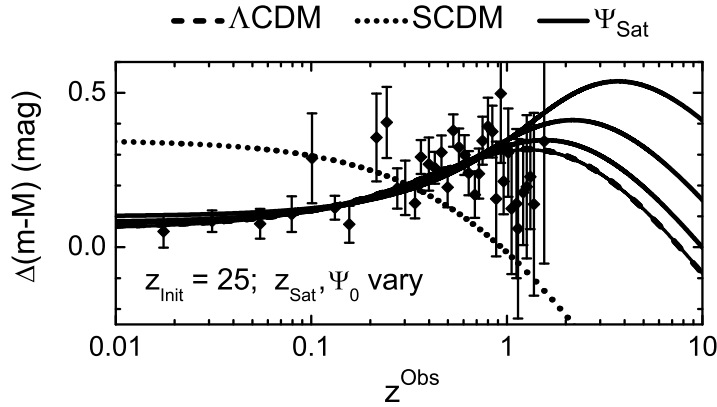


Fig. 2. Residual Hubble diagrams for models with different “clustering saturation” epochs ( $z_{\text{Sat}}$ ), with the ultimate degree of clustering ( $\Psi_0$ ) optimized for each case. Also plotted here are the binned SCP Union1 SNIa data points, along with flat SCDM and Concordance  $\Lambda$ CDM cosmologies.

Though successful at reproducing the ‘acceleration’, quite a large amount of clustering is needed – a nearly-complete clustering on several different hierarchical scales, simultaneously (... Stellar Clusters, Galaxies, Galaxy Clusters...). A more moderate amount of final clustering is sufficient, though, for models in which structure formation saturates at late times due to “gastrophysics” feedback, and due to clustering slow-down (still present in this formalism) from the ‘acceleration’ itself.

From the final results for our ‘best-fitting’ models found (even without a rigorous optimization), the output cosmological parameters were calculated, as would be seen by cosmic observers at  $z = 0$  (such as ourselves). These values are presented in Table 1, where it is clear that there are backreaction models for which all of the cosmological parameters considered here – including the observed Hubble Constant ( $H_0^{\text{Obs}}$ ), the observed age of the universe ( $t_0^{\text{Obs}}$ ), the matter density required for spatial flatness ( $\Omega_{\text{M}}^{\text{FRW}} = 1$ ), the characteristic angular scale of the CMB acoustic peaks ( $l_{\text{A}}^{\text{Obs}}$ ), and the strength of the apparent acceleration ( $w_0^{\text{Obs}}$ ) – are each broadly consistent with those from the  $\Lambda$ CDM cosmologies of the “Concordance Model”. It can therefore be concluded that a new, Alternative Concordance can indeed be achieved with Causal Backreaction, without any mysterious “Dark Energy” cosmic component being required. Finally, higher-order terms in the expansion ( $j_0^{\text{Obs}}$ , etc.) could potentially be used to distinguish between  $\Lambda$ CDM and Causal Backreaction.

Table 1. Output Cosmological Parameters from ‘Best’ Runs with Recursive Nonlinearities.

$z_{\text{Sat}}$	$\Psi_{0,\text{Opt}}$	$\chi_{\text{Fit}}^2$	$H_0^{\text{Obs}}$	$H_0^{\text{FRW}}$	$t_0^{\text{Obs}}$	$\Omega_{\text{M}}^{\text{FRW}}$	$w_0^{\text{Obs}}$	$j_0^{\text{Obs}}$	$l_{\text{A}}^{\text{Obs}}$
<i>Causal Backreaction simulation runs, with the beginning of clumping at <math>z_{\text{init}} = 25</math></i>									
0	4.1	311.8	70.07	42.32	13.64	0.943	-0.751	1.73	294.5
0.25	2.6	313.5	69.60	40.24	14.00	1.054	-0.620	0.15	289.7
0.5	2.3	316.6	69.40	36.32	14.65	1.338	-0.585	-0.14	279.8
1	2.2	320.2	68.77	29.54	15.75	2.086	-0.488	-0.94	259.9
<i>Comparison Values from the Union1-best-fit flat <math>\Lambda</math>CDM model (<math>\Omega_{\Lambda} = 0.713 = 1 - \Omega_{\text{M}}</math>)</i>									
—	—	311.9	69.96	69.96	13.64	0.287	-0.713	1.0	285.4

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